NASA TECHNICAL NOTE

NASA TN D-5342

c.1

NASA TN D-5342

SIMULTANEOUS USAGE OF ATTITUDE CONTROL FOR VTOL MANEUVERING DETERMINED BY IN-FLIGHT SIMULATION

by Frank R. Niessen

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JULY 1969

NASA TN D-5342

SIMULTANEOUS USAGE OF ATTITUDE CONTROL FOR VTOL MANEUVERING DETERMINED BY IN-FLIGHT SIMULATION

By Frank R. Niessen

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

SIMULTANEOUS USAGE OF ATTITUDE CONTROL FOR VTOL MANEUVERING DETERMINED BY IN-FLIGHT SIMULATION

By Frank R. Niessen
Langley Research Center

SUMMARY

A brief investigation was conducted with an in-flight simulator to obtain information pertinent to the nature of simultaneous attitude control usage. The amount of simultaneous control a pilot would use in performing various operational tasks in a vehicle with control response characteristics similar to those of a jet VTOL aircraft was measured. The simulation technique which was used in this study eliminated trim and disturbance effects. The simultaneous control usage for maneuvering was analyzed in terms of relative bleed-air demands.

The results of this investigation indicated that whenever high total usage did occur, it lasted for only a few tenths of a second. No simultaneous complete control demands occurred during any of the maneuvers; furthermore, the largest simultaneous control demands were significantly less than the sum of the individual maximum control demands.

INTRODUCTION

When jet VTOL aircraft operate at low speeds, they can no longer rely on the conventional aerodynamic control surfaces to produce adequate control moments. Rather, these aircraft must use reaction control devices. One type of control system which has been proved suitable is the jet reaction control system which uses high-pressure air bled from the engine. The bleed air is ducted to nozzles at the nose, tail, and wing tips, and by controlling the flow of bleed air through these nozzles, the pilot can produce control moments as required.

In designing the jet reaction control system, it is necessary that the amount of bleed air available for control be adequate to provide satisfactory handling qualities. The engine and reaction control system must be designed to meet this bleed-air requirement. However, any overdesign would introduce performance penalties. For instance, since the bleed-air jets absorb substantial amounts of energy directly from the installed power, a margin of thrust must be reserved for reaction control. Thus, an overestimation of bleed-air demand would result in an unnecessary requirement of the total thrust. Also, the sizing and weight of the control-system hardware would have to be greater to accommodate higher estimated bleed-air demands and, as a result the payload or the range may be significantly reduced.

For these reasons, simultaneous control demands, which relate directly to bleed-air demands, must be specified. Control requirements about individual axes have been extensively studied, but simultaneous control requirements have not been adequately investigated. At present, the only guideline is the AGARD recommendation (ref. 1) that full control be available about all three axes simultaneously. This recommendation is directed at the worst possible condition; although considerable evidence indicates that this recommendation is too severe, there is no agreement on a realistic requirement. Before firm requirements can be established, simultaneous attitude control usage must be further studied.

In order to obtain information pertinent to the nature of simultaneous control usage, a brief investigation was conducted at the Langley Research Center with an in-flight simulator. The purpose of the study was to measure the amount of simultaneous control a pilot would use in performing various operational tasks in a vehicle with control response characteristics similar to those of a jet VTOL aircraft. Although complete control requirements include trim, stabilization, and maneuvering requirements, simultaneous control usage for trim and stabilization was not measured in this study. The reason for this is that trim changes are a function of the specific aircraft configuration or type and, as such, must be determined on an individual design basis. Similarly, the effect of disturbances, such as gusts, is different for each particular type of aircraft. Therefore, simultaneous attitude control usage for maneuvering only was investigated.

EQUIPMENT AND PROCEDURE

The CH-46C in-flight simulator used in this study is shown in figure 1. The computer model simulation technique (ref. 2) was used to simulate the control response characteristics of a 15 000-pound jet VTOL (6800 kilograms) having no inherent stability but having a level of angular rate damping (as specified by ref. 1) provided by a stability augmentation system. The control sensitivities and levels of angular rate damping which were provided are listed in table I. The pilot commented that these control response characteristics were quite satisfactory for the test maneuvers performed.

Flight records of pitch, roll, and yaw angular accelerations were obtained during the various maneuvers. Since the simulation technique eliminated trim changes and resisted external angular disturbances, the angular accelerations which were recorded related directly to the maneuvering demands. It should be noted that the simultaneous control usage data in this investigation represent the actual demands placed on the simulated jet reaction control system by the pilot and the stability augmentation system. These data were analyzed to determine the extent to which simultaneous control usage had occurred.

TASKS

Flight records from a previous maneuver study (ref. 3) indicated that of all tasks performed, the S-turn maneuver was most critical in demanding substantially large control inputs about all three axes. Because of the possibility that a lateral quick-stop maneuver, which had not been included in the previous study, might be an even more demanding task, it was included in the series of maneuvers for the present investigation. Also, since the severity of the maneuvers, and hence the control requirements, could depend on the aircraft mission, tasks representative of both commercial and military operations were performed. The flight request was as follows:

1. Consider that you are flying a commercial VTOL transport carrying passengers. Perform the following tasks as expeditiously as you would consider practical under such circumstances.

   (a) Make a 3^{o} to 6^{o} approach at approximately 45 knots with a lateral offset of 300 feet. At about 300 feet from runway threshold, execute an S-turn maneuver to aline with runway and decelerate to hover at preselected spot on runway about 100 feet beyond the threshold.

   (b) Follow heading and altitude change commands issued by safety pilot, who will function as ground controller in the terminal area.

2. Consider that you are flying a VTOL transport in a military combat situation and are hauling troops and/or cargo. Perform the following tasks.

   (a) Repeat task 1(a) under these ground rules.

   (b) Fly an evasive course at low altitude to avoid enemy ground surveillance. Maintain speed at less than 60 knots. (A creek winding through a wooded area was found to be an ideal course.)

   (c) Perform lateral quick-stop maneuver in shortest distance with minimum gain in altitude.

DATA ANALYSIS

Records of the angular accelerations obtained in flight about the pitch, roll, and yaw axes were used to calculate control usage relating to bleed-air demand. It was assumed that for a jet reaction control system, the mass flow rate of bleed air is proportional to the resultant force produced at the nozzle, and the force at the nozzle is equal to the product of the moment of inertia and the angular acceleration, divided by the distance from the nozzle to the center of gravity; that is,

$$\begin{pmatrix}\text{Mass flow}\\ \text{rate of}\\ \text{bleed air}\end{pmatrix} \propto \begin{pmatrix}\text{Force}\\ \text{at}\\ \text{nozzle}\end{pmatrix} = \frac{\begin{pmatrix}\text{Moment}\\ \text{of inertia}\end{pmatrix}\begin{pmatrix}\text{Angular}\\ \text{acceleration}\end{pmatrix}}{\begin{pmatrix}\text{Moment}\\ \text{arm}\end{pmatrix}}$$

If, for a given aircraft, the inertia terms and moment arms are known, the bleed-air demand, which is proportional to the angular acceleration, can be calculated. Applying this relation to existing fighter-type jet VTOL designs indicated that about the same amount of bleed air is required to produce a given angular acceleration in pitch and yaw; whereas in roll, only about one-quarter as much bleed air is required to provide the same angular acceleration. Therefore, to compare the pitch, roll, and yaw control usage on an approximately equivalent bleed-air basis, the recorded roll control usage was divided by 4. The total control usage, that is, the simultaneous control usage, was thus defined as being equal to the sum of the pitch, one-quarter roll, and the yaw control demands at a particular time. Symbolically,

$$T = P + \frac{1}{4} R + Y$$

where T represents the instantaneous total control usage, and P, R, and Y represent the corresponding pitch, roll, and yaw control usage.

The results of this study are presented, first, in terms of time histories of the control usage for each axis (for the roll usage the one-quarter factor has already been introduced) and the instantaneous total control usage and, second, in terms of statistical plots which show the percent of time spent above various control usage levels for each task. These statistical plots are referred to herein as time distributions. This analysis was performed by a digital computer program with a sample rate of 10 samples per second. This sample rate was considered adequate to approximate a continuous distribution of the data for the frequency range of interest.

RESULTS AND DISCUSSION

The general nature of simultaneity of control usage is evident from the time histories in figure 2, which are typical plots for an S-turn performed for simulated military operation. Inspection of the time histories for pitch, roll, and yaw revealed that peak control demands occur for only one axis at a time; that is, simultaneous peak control inputs were not found to occur. As previously noted, total control usage, which is the instantaneous sum of the pitch, one-quarter roll, and yaw control usage, is a relative indication of the total bleed-air demand. It can be seen from this time history that the total control usage is of high frequency, and the peak demands are of very short duration. For example, it was determined that 25 percent of the time during the maneuver the total control usage exceeded a level of 0.185 radian/second^2 and that the average duration of peak demands above this level was 0.33 second. This is of significance because an engine can usually endure short-term excessive bleed-air demands without damage. Of further significance is the fact that peaks of such short duration would produce only minor changes in the aircraft response, perhaps so minor that they need not be provided for. Further study, however, would be required to determine whether this is true.

Curves such as those in figure 3, which show the percent of time spent above given levels of control usage, can be useful in understanding the degree to which simultaneity of control demands occurs. In this figure, the asterisk represents the sum of the largest individual pitch, roll, and yaw maximum control demands which were found to occur from a consideration of all maneuvers performed. This value, then, is the level of total control which would have been required if the individual maximums had ever occurred simultaneously. However, the results show that the maximum total control demand was only 53 percent of this value, considerably less than would have been anticipated on the more conservative basis. Similar results were obtained for the other maneuvers. These results are presented in table II; at most, 63 percent of the sum of the individual maximums is required for simultaneous control.

Of additional interest are the time distributions of total control usage for various maneuvers which are presented in figure 4. Unexpectedly, the S-turn maneuver which was performed for simulated commercial operation required larger maximum total control usage than the S-turn maneuver which was performed for simulated military operation, even though the latter was the more rapidly executed maneuver. However, the upper portions of the two curves do indicate that significantly high levels of total control were used longer during the simulated military maneuver. The reason for this anomaly appears to be that when dealing with higher angular accelerations, the pilot tended more toward control of one axis at a time. At lower angular accelerations overall, the pilot was more inclined to use simultaneous control inputs. Possibly, the pilot's ability to coordinate high angular rates was the major factor that limited the amount of simultaneous control he used.

CONCLUDING REMARKS

A brief investigation was conducted with an in-flight simulator to obtain information pertinent to the nature of simultaneous attitude control usage. The purpose of the study was to measure the amount of simultaneous control a pilot would use in performing various operational tasks in a vehicle with control response characteristics typical of a jet

VTOL having a reaction control system. It should be noted that the simulation technique eliminated trim and disturbance effects so that the control demands which were measured represented specifically the maneuvering demands. Simultaneous control usage was analyzed in terms of relative bleed-air demands and the following results were obtained:

1. High total control usage, when it did occur, lasted for only a few tenths of a second.

2. No simultaneous full control demands occurred during any of the maneuvers.

3. The largest total, or simultaneous, control demands were found to be significantly less than the sum of the individual maximum control demands. At most, only 63 percent of the sum of the individual maximums was used for simultaneous control.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 25, 1969,
721-06-00-03-23.

REFERENCES

1. Anon.: Recommendations for V/STOL Handling Qualities. AGARD Rep. 408A, Oct. 1964.

2. Garren, John F., Jr.; and Kelly, James R.: Description of an Analog Computer Approach to V/STOL Simulation Employing a Variable-Stability Helicopter. NASA TN D-1970, 1964.

3. Garren,John F., Jr.; Kelly, James R.; and Reeder, John P.: A Visual Flight Investigation of Hovering and Low-Speed VTOL Control Requirements. NASA TN D-2788, 1965.

TABLE I.- SIMULATION CONTROL RESPONSE CHARACTERISTICS

Attitude control	Control sensitivity, $\frac{\text{rad/sec}^2}{\text{in.}}$	Angular rate damping, $\frac{\text{rad/sec}^2}{\text{rad/sec}}$
Pitch	0.3	-0.5
Roll	0.4	-1.6
Yaw	0.2	-1.0

TABLE II.- MAXIMUM CONTROL USAGE FOR VARIOUS TASKS

Task	Maximum control usage, rad/sec^2				$\frac{T}{P^* + \frac{1}{4} R^* + Y^*} \times 100$, percent
	Pitch (P)	1/4 Roll (R)	Yaw (Y)	Total (T)	
Commercial S-turn	*0.27	0.11	*0.15	0.36	63
Terminal area	0.16	0.04	0.02	0.18	32
Military S-turn	0.25	0.13	*0.15	0.30	53
Evasive maneuvering . . .	0.18	0.09	0.13	0.25	44
Lateral quick stop	0.15	*0.15	0.12	0.25	44

*Largest individual maximum which was found to occur from consideration of all maneuvers performed.

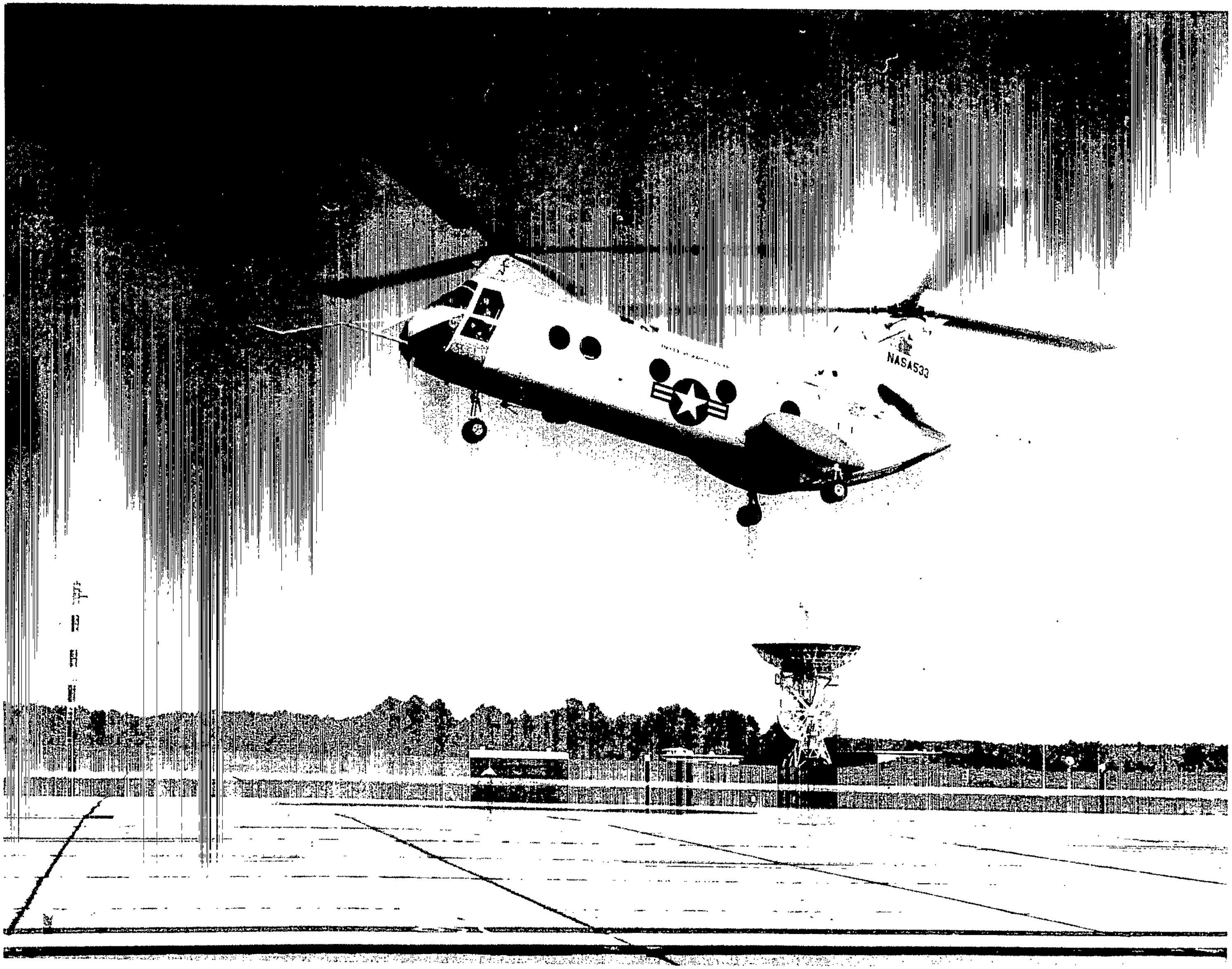

Figure 1.- The CH-46C in-flight simulator. L-68-9846

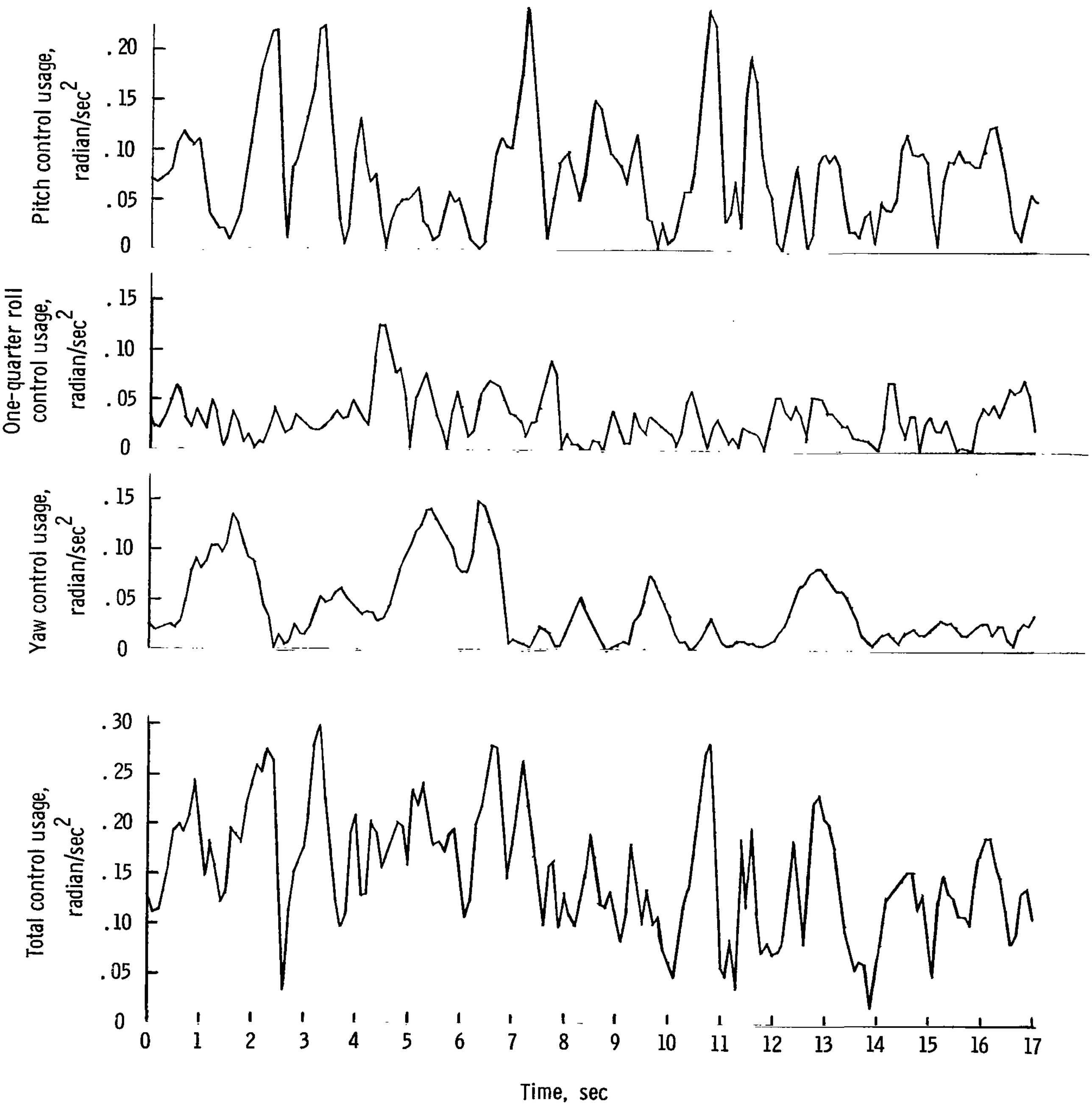

Figure 2.- Time histories of control usage for an S-turn (simulated military operation).

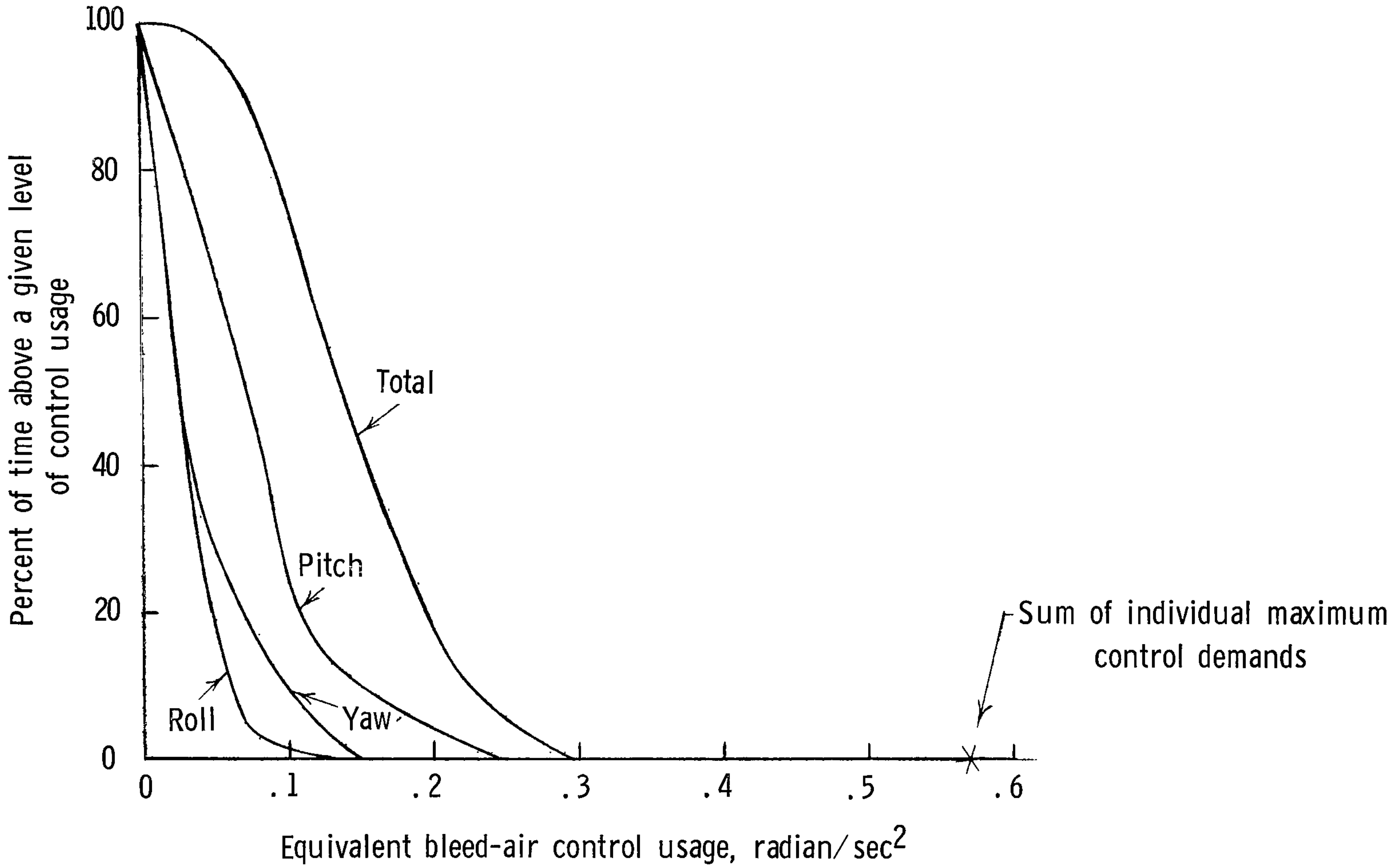

Figure 3.- Time distributions of control usage for an S-turn (simulated military operation).

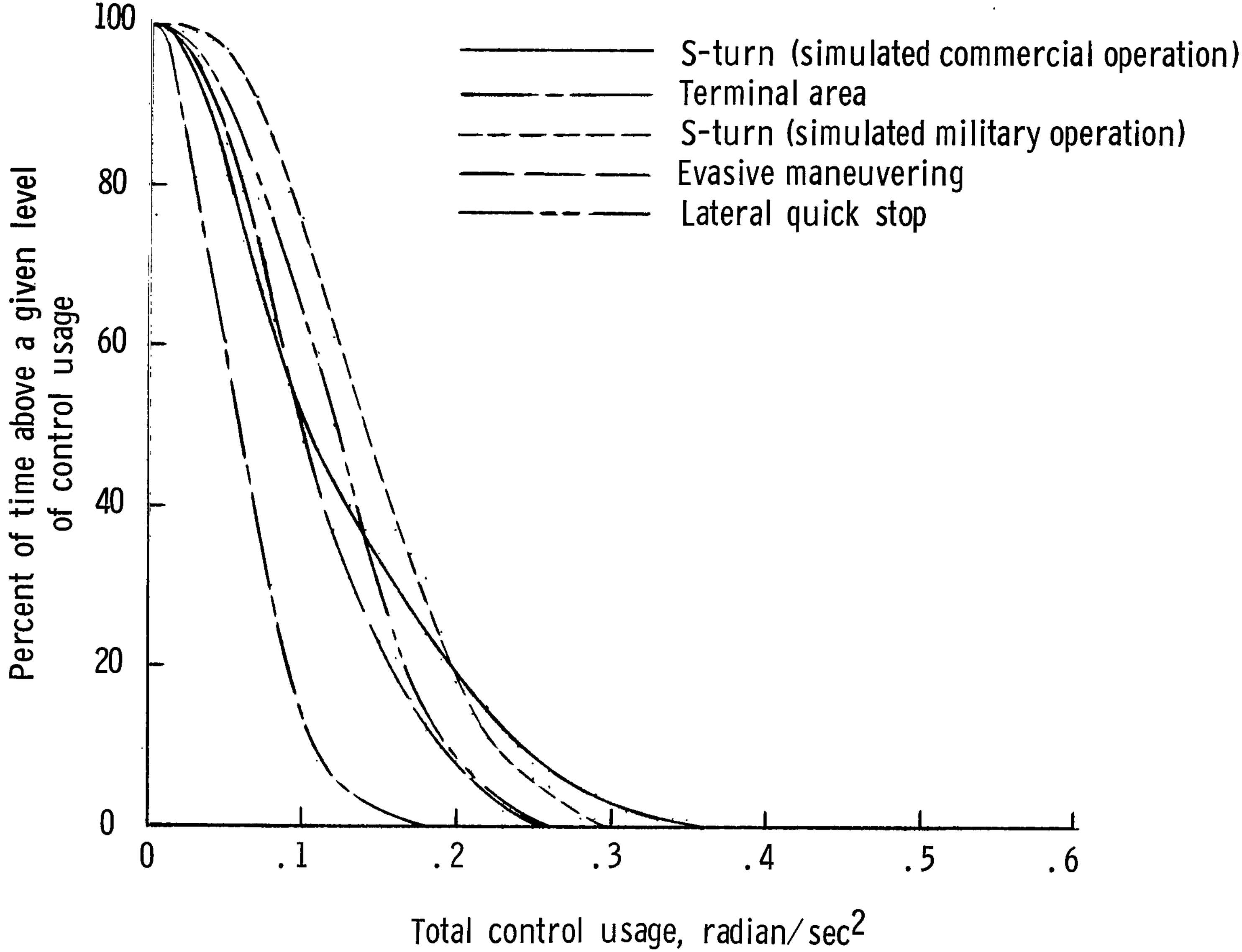

Figure 4.- Time distributions of total control usage for various tasks.

NASA-Langley, 1969 — 2 L-6568

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

---

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546